COTTON RESPONSE TO SHORT-TERM WATERLOGGING IMPOSED WITH A WATER-TABLE GRADIENT FACILITY

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ABSTRACT

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Waterlogging of field-grown plants can occur either when the surface of slowly permeable soils is inundated or when the water-table rises so that part or all of the root zone is saturated. The effects of short-term waterlogging on field crop growth and yield have not been well quantified. To study these effects, a sloping, repacked slab of soil underlain by an impermeable membrane was constructed. The sloping plot (45 m long × 6 m wide × 0.6 m deep) was flooded by introducing water through a drainage network and gravel bed so that a gradient of water-table depth ranging from 0.1 m above to 0.66 m below the soil surface was obtained. Cotton (*Gossypium hirsutum* cv. Deltapine 61) was grown in the facility and the responses of plants to two periods of flooding were monitored. Soil matric potential and oxygen partial pressure data indicated that plants were subjected to a continuum of conditions ranging from complete inundation to no water-table within the root zone.

The first flooding event began 82 days after sowing just prior to the main flowering period. Plants with more than 55% of their root system below the water table showed decreased leaf growth about 3—4 days after the flooding started with visible wilt symptoms and decreased leaf water potential observed on days 7 and 8 of flooding. In the second flooding event (131 days after sowing), plants showed no signs of waterlogging stress apart from reduced leaf growth despite 16 days of flooding. Plant growth response was probably more the result of reduced nutrient status (mostly nitrate) rather than a water deficit stress effect with some plant acclimatization between the first and second flooding event. Seed cotton yield data indicated that the observed stress during the first flooding event may have promoted reproductive growth in plants where the short-term water-table was greater than 0.2 m below the soil surface.

INTRODUCTION

Waterlogging of a crop root zone can be induced either by continual surface addition of water to slowly permeable soils or, more commonly, by a rising water table within the soil profile. While the general effect within the root zone of low soil oxygen availability may be the same (Kramer, 1969), the time course of these two processes can be different. Rapidly induced waterlogged conditions will generally occur when water is ponded on the soil surface although the introduction of a rapidly rising water table will have the same effect.

Although a reasonable amount of information is available which describes the response of plants to the presence of static water-tables (Hiler, 1969; Williamson and Kriz, 1970; Meek et al., 1980; Alvino et al., 1983), little information is available which describes plant response to rapidly imposed, short-term periods of waterlogging under field conditions.

Hodgson and Chan (1982) found an 8% decrease in cotton lint yield when the period of inundation by irrigation increased from 4 to 16 h. If this inundation period increased to 32 h, an 18.3% decrease in lint yield occurred (Hodgson, 1982). De Bruyn (1982) found seed cotton yields decreased by 42% as the result of excess water application which resulted in ponding for up to 4 days at each irrigation. For wheat, Meyer et al. (1985) found a yield decrease of 40% between treatments which were flooded for up to 3 days on three separate occasions and those that were not. Thus, short-term periods of waterlogging can reduce crop yield, and therefore, may be important in limiting yields of crops grown on slowly permeable, surface-irrigated soils (Mason et al., 1983; Smith et al., 1983).

The relations between leaf water potential and leaf diffusive conductance established during drought stress may not apply when stress is induced by waterlogging. Further, most experimentation thus far has been with plants in controlled environments with low evaporative demand, where in general, relatively small root volumes are rapidly subjected to changes in the root zone environment. Apart from the work of Meek et al. (1980), the response of cotton plant water status to waterlogging in controlled field experiments has received little attention.

Quantifying plant response to rapidly imposed, short-term waterlogging in the field is hampered by the difficulty of generating a range of treatments. Some studies have been done in controlled facilities such as rhizotrons (Stanley et al., 1980) or small lysimeters (Hiler, 1969) where water-tables were imposed on the root zone for discrete time periods. In an attempt to obtain a wide range of waterlogging treatments in the field a facility was designed which allows a continuum of water-table heights to be rapidly imposed and removed from a test crop. Thus, plant responses to a range of waterlogging conditions in the field, from complete inundation to the absence of a water-table within the root zone, can be studied. This paper describes the facility, the root zone conditions and the response

of cotton leaf growth, leaf water status and yield to two short-term periods
of waterlogging.

MATERIALS AND METHODS

   The variable water-table depth facility, constructed at the CSIRO, Center
for Irrigation Research, Griffith, N.S.W., Australia (34°17'S, 146°03'E),
consisted of an impervious barrier under a repacked slab of soil (45 m
long × 5 m wide × 0.6 m deep) with a slope of 1.78%. The schematic
diagram is shown in Fig. 1. The soil used was the top 0.6 m of a Hanwood
loam (Butler, 1979), a freely draining horticultural soil containing up to
58% clay with a pH range of 6.9—7.8.
   Facility construction was accomplished with a hydraulic backhoe and
a front-end loader. The top 0.2 m of soil was removed and stockpiled sep-
arately from the remaining subsoil. The main excavation by the backhoe
resulted in sides of slope 45° with the bottom width of 3 m sloped to the
prescribed longitudinal grade. The bottom of the trench was made smooth
with a 0.1 m layer of fine sand. Impermeable Polyfabric was then laid in
the trench. Two lengths of slotted, rigid PVC drain pipe (100 mm OD)
were laid on top of Polyfabric along the full length of the trench and were
connected to the water control structure at the lower end. Small rounded
pea gravel and then coarse gravel was laid on top of the Polyfabric to a depth
of 0.15 m. The water control structure and attached pipes embedded in
the gravel allowed for the rapid addition and removal of water at the begin-
ning and end of a flooding event. Once the gravel was levelled to the pre-
scribed grade, the subsoil was replaced and spread to a depth of 0.4 m.
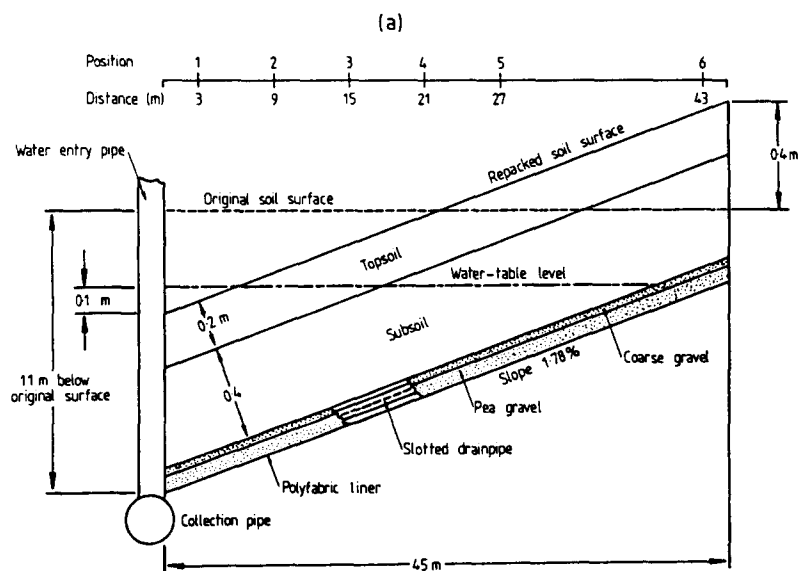The topsoil was then repacked to a depth of 0.2 m to give a 0.6 m total

(a)

Fig. 1a (For description see page 130)

depth of soil. The soil around the perimeter of the facility was graded smooth and the edge of the Polyfabric secured onto a wooden frame where the soil surface inside the facility was lower than that of the surrounding soil. A control plot the same size was established adjacent to the facility. Plants in this control plot grew in disturbed soil but with no impermeable barrier and free internal drainage. Except for the flood events, the sloping plot and control plot were treated the same.

Upon completion of the facility, fertilizer was broadcast at the rate of 130 and 100 $kg\,ha^{-1}$ for N and P_2O_5, respectively, and incorporated in the top 0.1 m of soil. Cotton (*Gossypium hirsutum* cv. Deltapine 61) was planted on 26 October 1982. Conventional herbicide and insecticide management ensured a healthy crop. Sprinkler irrigation was used to maintain a well-watered soil water regime within the sloping plot, the control area and a 3 m wide border area throughout the entire growth cycle. Irrigation was applied when tensiometers at a soil depth of 0.15 m indicated −30 kPa. The amount applied was equal to the cumulative pan evaporation measured at a weather station 300 m from the experimental site.

Because the water-table depth varied on a continuous basis, six positions

Fig. 1. Schematic drawing of the variable water-table facility: (a) longitudinal cross section (note that the vertical scale is exaggerated); (b) cross-sectional elevations at seven positions.

along the facility were selected for detailed instrumentation and plant measurements to cover the range of water-table depths. The six positions were 3, 9, 15, 21, 27 and 43 m from the lower end of the facility. The water-table depth at each of these positions were designed to be 0.04 m above the soil, and 0.05, 0.17, 0.27, 0.38 and 0.66 m below the soil surface, respectively. At all measurement positions, mercury manometer, ceramic-tipped, tensiometers were installed at depths of 0.15, 0.30 and 0.45 m. Sintered-bronze soil-air sampling tubes fashioned after those of Dowdell et al. (1972) were installed at 0.1, 0.2, 0.35 and 0.55 m below the surface. Samples of soil-air or soil-water were analyzed for oxygen using a platinum oxygen electrode. The mini-rhizotron technique of Bohm (1974) was used to characterize root distribution at each position. Clear acrylic cylinders (0.1 m I.D.) with horizontal lines etched every 0.05 m to the 0.60 m depth of soil were used to observe the root distribution. The number of roots intersecting each of the lines was counted periodically during the growing season with increased frequency around the two planned flooding events. Because the root counts at the start and end of the flood events were essentially the same, the mean value was used to calculate the proportion of roots below the water-table.

Two flooding events were used to evaluate the performance of the facility. The first began on 17 January 1983 (83 days after sowing) when complete canopy cover had been established. Water was pumped into the facility through the water control structure and the level was maintained by a float valve. The first flooding was maintained until 25 January 1983 when visible wilt symptoms were observed at midday on some plants growing in the completely inundated area. The water-table was then removed. Following the first flooding period, plant recovery was aided by applying additional nitrogen (75 kg ha^{-1} N as urea) and uniform sprinkler irrigation.

The second flooding event started on 7 March 1983 (132 days after sowing). The water-table was maintained until 23 March although no visible signs of plant stress occurred.

PLANT MEASUREMENTS

On, or slightly before, the start of each flooding event, daily measurements of plant growth and water status began. Measurements were confined to plants within 1 m of each of the six selected positions along the sloping plot. Complementary measurements were made on plants in the control plot.

Leaf growth was monitored by measuring the length of the leaf lamina from the petiole junction to the central apex of the top five leaves on the main stem of each of three plants at each position. Daily growth of each of the five leaves was accumulated to give a total growth for the plant. Mean cumulative growth was then calculated from the three plants over time.

Water status measurements were generally made around solar noon except for several days during the first flooding event when predawn observations were also made. Leaf water potential (ψ_1) was measured with a pressure chamber. Uppermost, fully developed leaves (four to six per position) were randomly selected and covered with a polyethylene laminated aluminum foil bag (Meyer and Reicosky, 1985) immediately prior to excision and were transported to the pressure chamber inside a second larger, humid, reflectively covered plastic bag. The leaf with the petiole protruding remained in the laminated foil bag throughout the measurement which was generally completed within 2 min of excision.

Plant nutritional status was monitored during each of the flooding periods by daily sampling 25 petioles from each position. These samples were dried, ground and extracted for nitrate N and total P analyses (see Hocking et al. (1985) for details).

RESULTS AND DISCUSSION

During the 1982—83 experimental season, little rainfall occurred and so irrigation was applied up to mid-April 1983. When the flooding events were initiated, water pumped into the water control structure rapidly moved through the soil profile and was visible above the soil surface at the lower end of the facility within an hour. The total amount of water needed to flood the system to the prescribed height (0.1 m above the soil surface at the lower end) was about 22 m^3. While the float valve was adequate for maintaining the water-table, an automatic system to drain excess water accumulating from surface irrigation and rainfall would in hindsight have been advisable. Free surface water was visible for 4—5 m from the lower end of the plot while the water-table was maintained. It was intended to check water-table levels along the facility with the root observation tubes. This proved to be unsatisfactory so a series of 45 mm diameter holes were used. Readings indicated that free-water was maintained within 50 mm of the planned level.

Profiles of soil matric potentials as measured by the tensiometers indicated saturated conditions up to position 4. Because the profiles were not descriptive, the time course of the mean of the three potentials at three positions are shown in Fig. 2. Clearly, the presence of the water-table and associated capillary rise in the profile up to position 4 caused most of the profile to be at or very near saturation. There was fluctuation in matric potential at position 6 since alternate wetting and drying occurred as the result of sprinkler irrigation (indicated by arrows in Fig. 2) and plant water extraction. It appears that the sprinkler irrigation was in excess of plant requirements since the two lower tensiometer readings at position 6 progressively increased during the flooding period. There may have also been some lateral unsaturated soil water movement from position 5 toward position 6 within the sloping plot. Similar results were obtained in the second flooding event and are not shown.
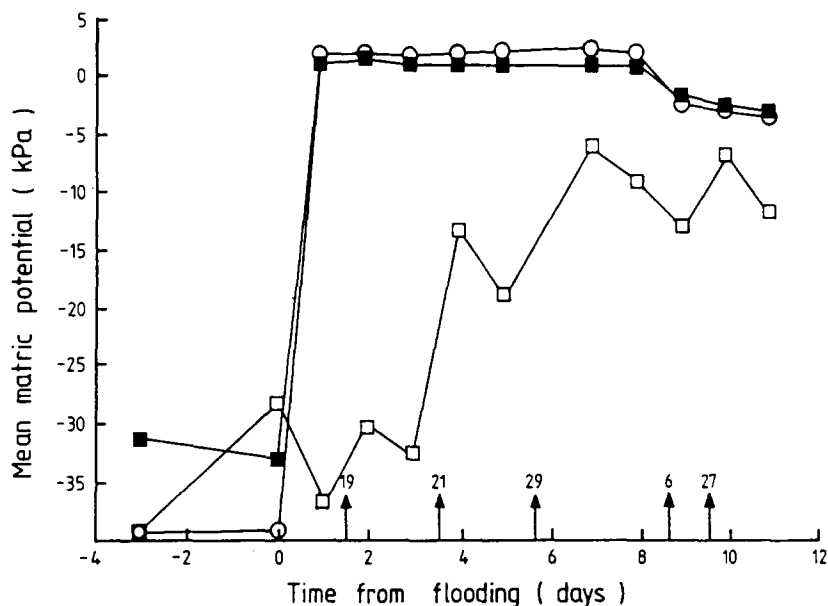
Fig. 2. Mean matric potential at positions 2 (○), 4 (■) and 6 (□) as a function of time during the first flooding event. Arrows with associated numbers indicate sprinkler irrigation events and the amounts (mm) applied.

The mean partial pressure of soil oxygen during both flooding events at the same three positions as in Fig. 2 are summarized in Fig. 3. In the first flooding event (Fig. 3a) both positions 2 and 4 showed a rapid decrease in soil oxygen 2 days after the water-table was imposed. Position 4 had mean values which were greater than at position 2 during the first 8 days because of higher partial pressures of oxygen in the top soil layer. While some of the individual data points were relatively low, none showed zero partial pressure of oxygen. The scatter in the mean values of soil oxygen during the flooding event when the soil water status was constant reflects the high spatial variability which is an inherent feature of soil aeration measurements (Fluhler et al., 1976). Position 6 showed slight depressions in the mean partial pressure of soil oxygen ranging from 16 to 18 kPa as a result of the frequent, sprinkler applied irrigations.

A similar time trend for mean partial pressure of soil oxygen occurred during the second flooding event (Fig. 3b). Again, mean values for soil oxygen never decreased to zero even after 16 days of flooding. The mean soil oxygen at position 6 again remained between 16 and 18 kPa during most of the flooding period except for a large decrease 16 days after flooding which was associated with a heavy irrigation applied on two consecutive days.

Prior to the first flooding, plants along the water-table gradient facility appeared to be quite uniform both in color and morphology. Plants were about 0.6 m high with complete canopy coverage. There were some plants
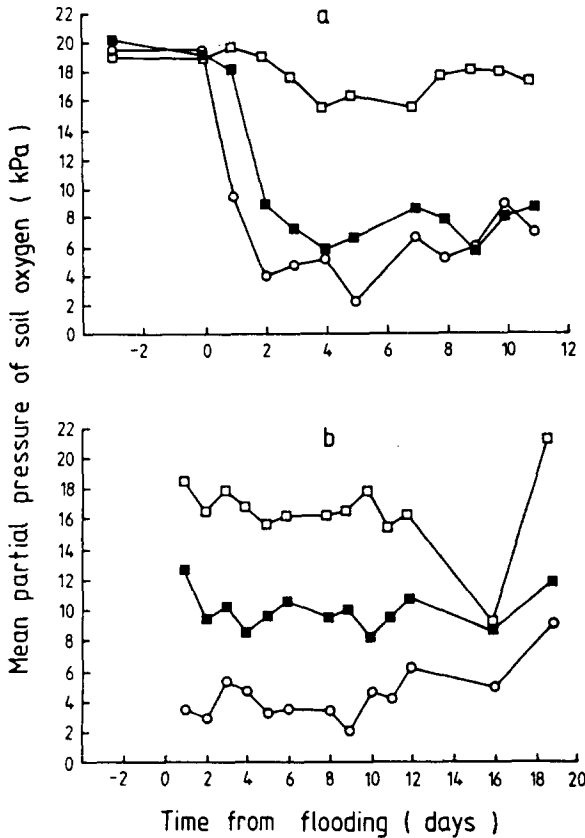
Fig. 3. Mean partial pressure of soil oxygen for the same positions as in Fig. 2 as a function of time during: (a) first flooding event; and (b) second flooding event. Symbol descriptions are the same as Fig. 2.

at the lower end (near position 1) which were slightly smaller and less green. This was probably due to the effects of surface runoff accumulating at this point following regular sprinkler irrigation. During the first 4 days of the flooding period, no visible change in plant character was noticed. On about the 5th day some changes in color (a slight 'greying') of the leaves from position 4 and below was noted. It was not until day 7 that clearly visible wilt symptoms of leaf flaccidity were present in all positions except 5 and 6. One of the peculiar features of this wilt was the nonuniformity among plants at a particular position. Even on day 8 only about 80% of plants in positions 1 (water-table 0.04 m above the soil surface) to 4 (water-table 0.27 m below the soil surface) showed visible wilt.

At the beginning of the second flooding period, plants along the sloping plot were about 1.2 m high and reasonably even in appearance although those in positions 1 to 4 had slightly smaller upper leaves and tended to have a slightly more vertical leaf orientation. During the whole of the second flooding period, no major changes in plant appearance occurred except

for three randomly distributed plants which died in the area around position 1 where free water existed on the soil surface.

During the first flooding period, leaf growth patterns formed three groups (Fig. 4a). Position 1, where water was 0.04 m above the soil surface had the lowest growth rate overall. When compared to position 6 (water-table 0.66 m below the soil surface), the reduced growth rate at position 1 became apparent on day 4 after flooding. The decreased growth rate may be associated with the low partial pressures of oxygen measured 2—4 days after flood initiation (Fig. 3). Positions 2, 3 and 4 had almost identical patterns of growth and appeared to diverge from the third group, positions 5 and 6, between days 3 and 4. For the second flooding period (Fig. 4b), three groups similar to those in the first flooding also emerged. Again position 1 had the lowest overall growth rate with the divergence from position 6 beginning 2 days after flooding.
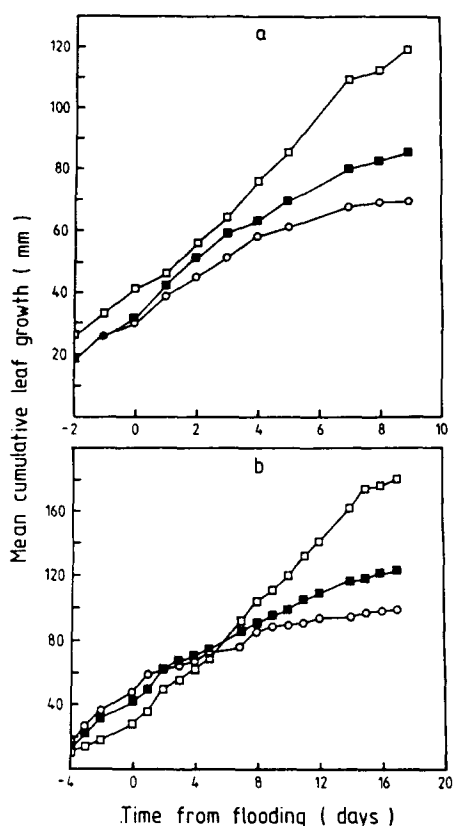

Fig. 4. Mean cumulative leaf growth at positions 1 (○), 4 (■) and 6 (□) after the imposition of the first (a) and second (b) flooding periods. Note the change of scales between the two flooding periods.

The response of cotton plant water status to the two flooding events is summarized in Fig. 5. In general, values of leaf water potential (ψ_1) changed little with respect to water-table depth and duration of flooding. Predawn ψ_1 in the first flooding remained the same (mean value of -0.53 ± 0.04 MPa) regardless of water-table depth throughout the flooding period and is represented in Fig. 5a by the data from day 7. Midday ψ_1 also changed little with respect to water-table depth during the first 6 days of the first flooding period as illustrated by the midday ψ_1 for day 0. Only when visible wilt was evident on days 7 and 8 was the cotton ψ_1 with high water-tables different from the control or nonstressed plants. The nonuniformity of wilting of the randomly sampled plants below position 4 is reflected in the large standard deviation bars on day 8.

For the second flooding period midday, ψ_1 again remained very steady along the sloping plot with day-to-day fluctuations being associated with changes in evaporative conditions since the same fluctuations occurred in the control plants (Fig. 5b). There was a suggestion on day 2 of the second
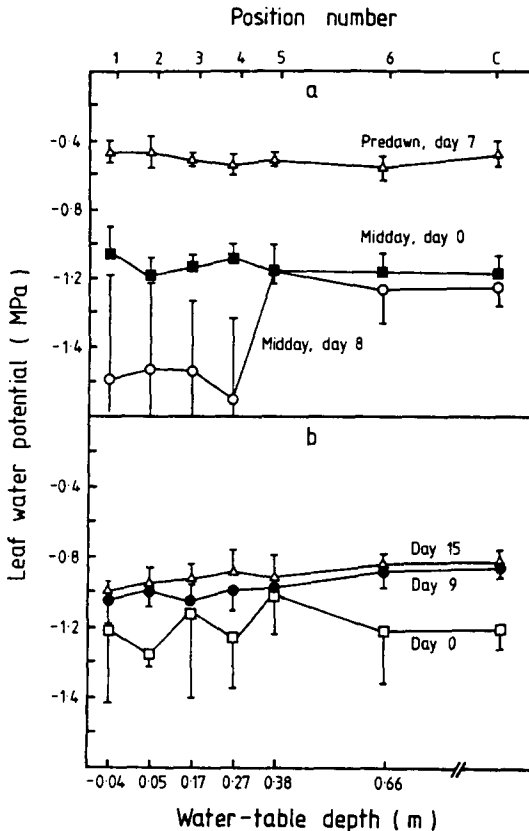

Fig. 5. Leaf water potential during the first (a) and second (b) flooding periods. Bars at each point are standard deviation (SD) values. For clarity, only half the SD is shown in most cases. For comparison, control area values are plotted under position 'C'.

flooding period that the mean ψ_1 of positions 1 to 4 (-1.42 ± 0.08 MPa) was less than the mean ψ_1 of positions 5 and 6 (-1.18 ± 0.13 MPa). However, this apparent difference was not sustained in the subsequent days. The lack of any difference in ψ_1 with respect to water-table depth may have been the result of changes in leaf morphology and physiological activity as an adaptive response to the first flooding. Subtle differences in leaf morphology were noted with upper leaves below position 4 being slightly smaller.

Plant nutrient analysis (Hocking et al., 1985) indicates that in both flooding periods plants from nearly all sloping plot positions. showed a decline in the amount of nitrate-N and P found in the perioles (Table 1).

TABLE 1

Percentage change during the flooding period in nitrate N and total P in perioles

	Position number		
	1	4	6
First flooding (days 1 to 7)			
Nitrate N	−76.0	−64.4	−52.5
Total P	−56.0	−46.0	−40.4
Second flooding (days 0 to 15)			
Nitrate N	−98.0	−74.7	−19.4
Total P	−54.0	−41.3	−34.5

However, the decreases in the nutrient levels were always much greater at those positions with high water-tables. Absolute nitrate-N levels at the beginning of each flooding period (mean 1.04 and 0.5% on a dry mass basis for the first and second flooding events, respectively) were not particularly high, and certainly by the end of each flooding period, all levels were low with those at positions 1 to 4 being indicative of very N stressed plants. Hearn (1981) states that petiole nitrate levels less than 0.2% are indicative of nitrate deficiency. Total P levels (mean values of 0.2 and 0.26% for the first and second flooding events, respectively) were generally in the sufficient range but again positions 1 to 4 approached insufficiency (values $< 0.1\%$; Hearn, 1981) at the end of each flooding period. More details of the nutritional status of the plants are presented elsewhere (Hocking et al., 1985) but in general, rapid decreases in the levels of petiole nitrate and total P occurred between days 4 and 5 after flooding began and were apparently associated with the decrease in leaf growth (Fig. 4).

The number of root intersections counted in the mini-rhizotrons above or below the water table were expressed as a percent of the total in the 0.6 m profile and plotted as the percent of the roots below the water-table

(Fig. 6), at each of the six measurement positions. In the first flooding event the percent of roots below the water-table from positions 2 to 6 showed a linear decrease as the water-table depth increased. Up to this time, the roots had been growing under ideal conditions which resulted in a relatively uniform root distribution with depth. However in the second flooding event, the root distribution had changed so that a lower percentage of the root system was below the water-table. Apparently, the first flooding event was severe enough to result in some root death which altered the distribution. This occurred, despite attempts to keep the soil water status uniform and near optimum during the period between the flooding events.
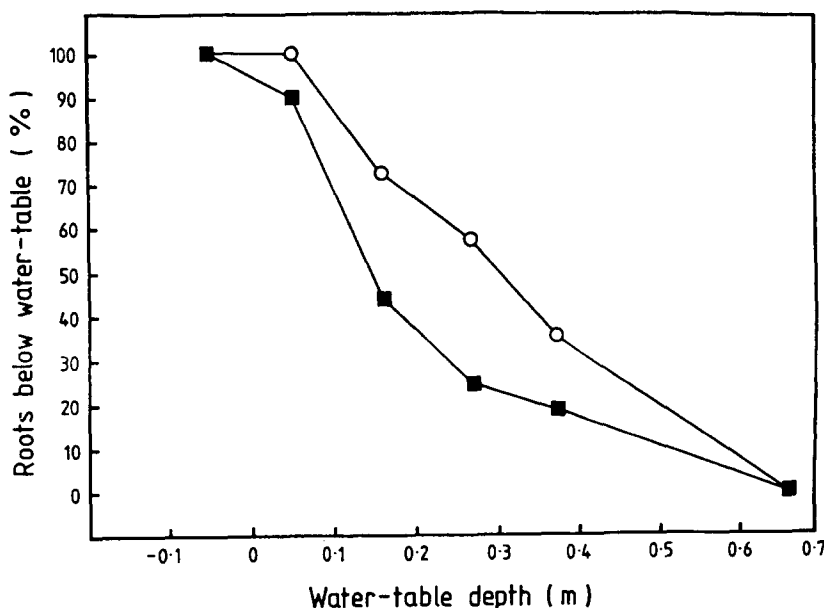

Fig. 6. Percentage of roots below the water-table as a function of water-table depth for the first (○) and second (■) flooding events.

The mass of seed cotton determined from the final harvest of 1-m² areas on 25 May 1983 is shown in Fig. 7. Yield was closely associated with the final boll number ($r^2 = 0.70, P < 0.001$). The shape of the yield response along the sloping plot was unexpected and does not appear to be related to the growth responses observed during the two flooding events. The maximum yield was obtained where the intermittent water-table was between 0.1 and 0.3 m below the soil surface. A sharp yield decline was noted with shallower water-table depths while a more gradual decline was noted with deeper water-table depths. While there is some scatter in the data, the shape of the yield response to the intermittent water table lacks a clear explanation leaving any conclusions tenuous. However, if the yield data at the very low end of the sloping plot (where water completely in-

undated the soil surface) are omitted, a significant ($P < 0.001$) linear regression can be fitted. The data from this portion of the sloping plot suggests that there was a 50% yield advantage for those plants which were intermittently stressed by the introduction of a water table into their root zone. Alternatively, those plants where the water table was at an increasing depth may have been subjected to yield-reducing water deficit stresses. This effect was most unlikely because frequent irrigations based on tensiometer readings ensured that the facility was kept well watered.
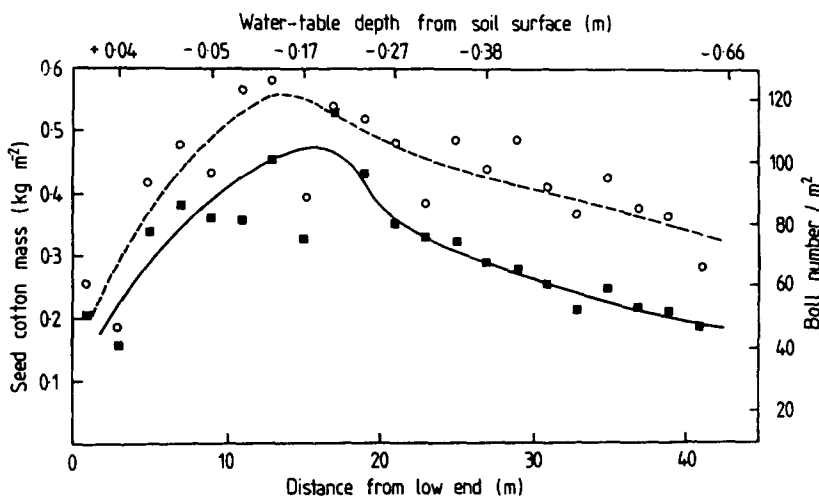
Fig. 7. Seed cotton yield (■) and boll number (○) versus water table depth. The lines through the data points were drawn by hand to illustrate the trends.

DISCUSSION

A few features of this experiment were noteworthy. The 4—5 days required for plants in the first flooding period to begin responding was much longer than had been expected based on controlled environment work. These results were unexpected given that atmospheric evaporative demand was quite high (average daily pan evaporation was 9.8 mm). When the visible plant response occurred, it did so with a distinct break about 2 m up from position 4. At this position, the water table was 0.32 m below the soil surface with 45% of the root system above the water table. With capillary rise, a larger portion of the root system should have been exposed to nearly saturated conditions. Another feature of the response was the lack of uniformity in the plants at any particular position. Thus, on day 8 only a few plants were severely wilted, most others appeared to be wilted while others seemed to be unaffected. The exact cause of this effect was not determined and we can only surmise that it was due to individual plant variability caused by both genetic and phenotypic differences or other differences associated with special variability within the facility. The other

noteworthy feature was the nonrepeatability of the two flooding events. Presumably some acclimatization and conditioning occurred following the first flooding which better enabled the plants to cope with the second flooding event. Observed changes in root distribution (Fig. 6) may be involved.

During the first flooding period, the decrease in growth of leaves was not consistently associated with decreased ψ_1. Our observations suggest that the initial wilt symptoms were not caused by poor plant water status as measured with the pressure chamber and that only when plants were severely wilted did ψ_1 decrease (on day 8 of the first flooding event). Partial closure of stomata on and after day 5 of the first flooding event was sufficient to cause an increase in foliage temperature (Reicosky et al., 1985). Thus, the relationship between foliage temperature and ψ_1 (Idso et al., 1982) may not operate when increases in foliage temperature are caused by waterlogging.

For the second flooding event the reduction in leaf growth again began about 2 days after flooding and was apparently not mediated by decreased ψ_1. The reason for the reduced growth may be associated with the rapidly declining nutrient levels where petiole N, in particular, reached deficiency levels at the end of each flooding period. The interaction between N deficiency and water deficit stress physiology has been studied in the drought situation (Radin and Parker, 1979) and some of their findings are relevant here. They concluded that stomata of N-deficient plants were more sensitive to stress. The coincidence in time of decreased leaf growth and low petiole nitrate levels suggests that the interacting control mechanisms discussed by Radin and Parker (1979) were also operative where plant stress was induced as the result of waterlogging.

Consideration of the above data suggests that the primary response of cotton plants subjected to waterlogging stress in the field is not immediately mediated through effects on plant water status. This is in contrast to the general conclusion reached by Cannell (1977, p. 13) and may reflect differences in the response of different species to waterlogging stress. If water uptake is mainly a passive process (i.e., not requiring O_2) then this will continue despite impairment of the active uptake functions of the root. However, this impairment of active functions will very likely affect nutrient uptake and root hormone production more readily than water uptake. Thus, the present results are consistent with the premise that waterlogging stress primarily causes a direct reduction in active (energy requiring) root processes such as nutrient uptake resulting in decreased leaf growth and a delayed effect on plant water status.

Even though the plant measurements indicated that some stress occurred (mainly during the first flooding event) its subsequent effect on plant yield appears to have been beneficial. This response in cotton is not unknown (Hearn, 1980) although there is some confusion about the extent of the effect. Those experiments which do report yield increases as the result of drought stress indicate that the stress occurred prior to flower-

ing. In the present experiment, the first flooding event with measurable imposed plant stress was prior to the main flowering period which subsequently occurred when water was nonlimiting and additional nitrogen fertilizer was supplied.

CONCLUSIONS

The basic concept of using a sloping plot to impose a variable water-table depth was successful and provided a range of soil water and oxygen levels where cotton plants had various portions of their root system under waterlogged conditions. Two flood events in the growing season showed similar soil water and oxygen profiles with the plant response more dramatic in the first flooding. Soil oxygen partial pressures decreased to low values within two days of the water-table being imposed, but none showed complete oxygen depletion. About 55% of the root system needed to be under the water-table before visual effects were observed in the plant canopy. Unacclimatized plants in the first flooding exhibited a reduction in leaf growth rates and eventually exhibited decreased leaf water potentials and visible wilt symptoms. The first flood event altered the root distribution to such an extent that plant water status in the second flooding was not affected. The observed stress and decreased leaf growth in both flood events appeared to be associated with a decrease in N uptake during flooding. The interactions of nutrient stress and other stresses experienced by the plant were not clear. Seed cotton yield, was largest where the intermittent water table during the two flood events was between 0.1 and 0.3 m below the soil surface. Should these stress effects occur prior to the major flowering period small reductions in vegetative growth may result in the promotion of reproductive growth. These results demonstrate plant tenacity and the ability to acclimatize to waterlogging events to the extent that subsequent waterlogging exposure of previously waterlogged plants may have little detrimental effect. The variable water table depth facility enables study of plants subjected to a continuum of conditions ranging from complete inundation to a complete absence of a water-table within the root zone and may prove useful as an aid to screening plant genotypes for their tolerance to rapidly imposed waterlogging events.

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